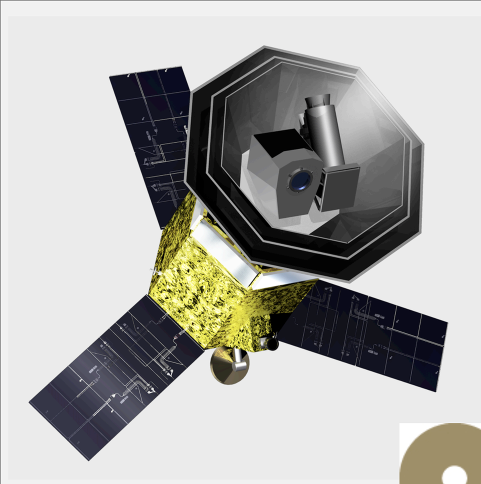

LCS: Feasibility Study for a Calibration Satellite to enhance LiteBIRD science

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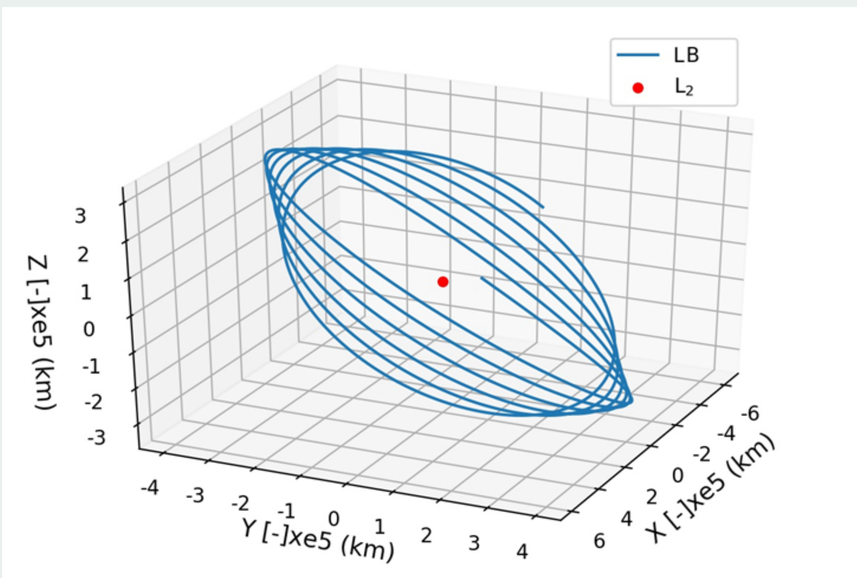
Mission Analysis



LB trajectory around L_2.

LCS Mission

Formation flying of LCS and LB for periodic calibration.

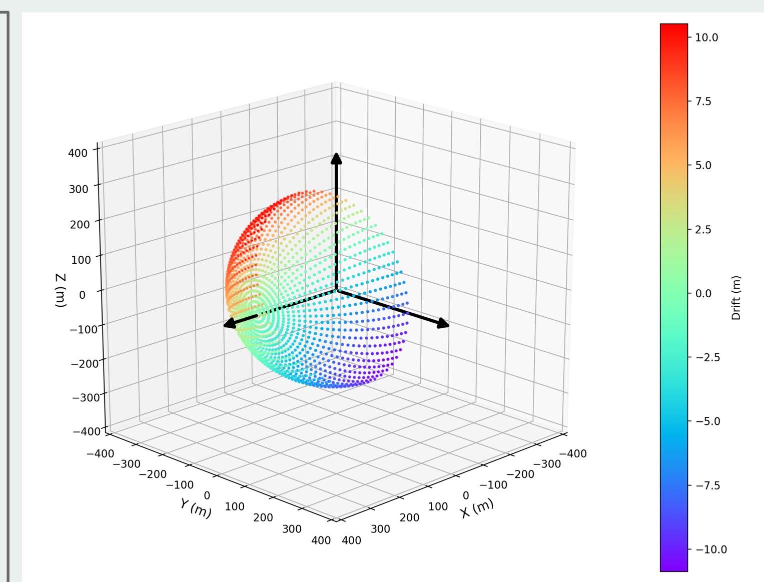
Maneuvers:

Orbit maintenance maneuvers keep formation:

- Maneuvers required periodically during the 3 years of mission.
- L2 presents low force gradients.
- **Very low ΔV (~1 m/s per year).**

Formation maneuvers. **Drift** for short time periods (**1 day**) without applying control is lower than **1 m** near to **anti-sun axis**. Precise **maneuvers** can reduce the drift to **1 cm** per **day**.

Two options have been considered for the mission. A deployment from LB of a CubeSat or an independent satellite deployed from the same launcher. In the last case a transfer to L2 is required and ΔV budget changes significantly.



Drift of LCS for different positions, relative to LB during one day of simulation.

ΔV budget for main and alternative options.

Activity	Main ΔV (m/s)	Alternative ΔV (m/s)
Transfer from parking orbit to L_2	-	293
Orbit maintenance	3	3
Relocation maneuvers	3	3
Formation maneuvers	1	1
Deployment	0.25	-
Wheels desaturation	1.25	1.25
Margin (5%)	0,425	15
Total	≈ 9	≈ 317

Calibration

Calibration strategy analysis I

Positioning maneuvers. LCS must be inside LB's FoV during calibration and move away at finishing.

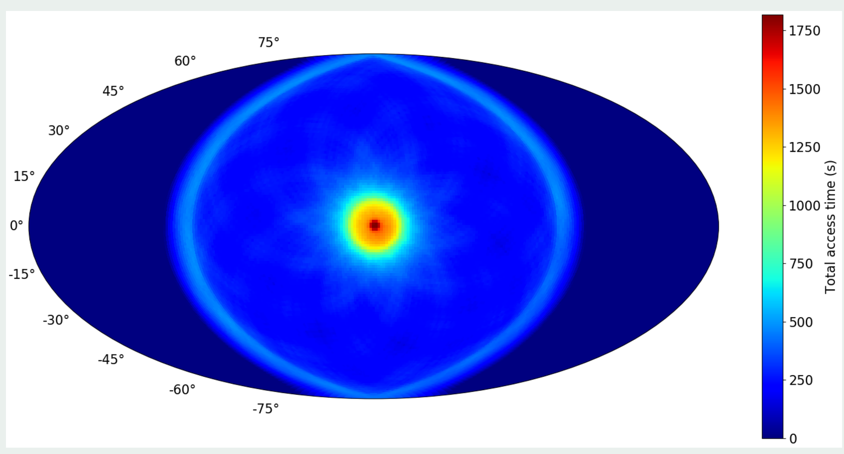
- 4 impulses for each calibration manoeuvre.

LiteBird scanning law and LCS relative position define:

- Total access time.
- Number of viewed LB instrument detectors.

Total access time is proportional to the number of accesses and how the signal crosses the focal plane.

- If LCS has a right ascension higher than roughly 15º the waiting time between accesses would be equal to one precession period.
- Average access time is uniform and around 30 s, regardless of the LCS position.



Total access time according to the position of LCS relative to LB throughout 12 hours.

Calibration strategy analysis II

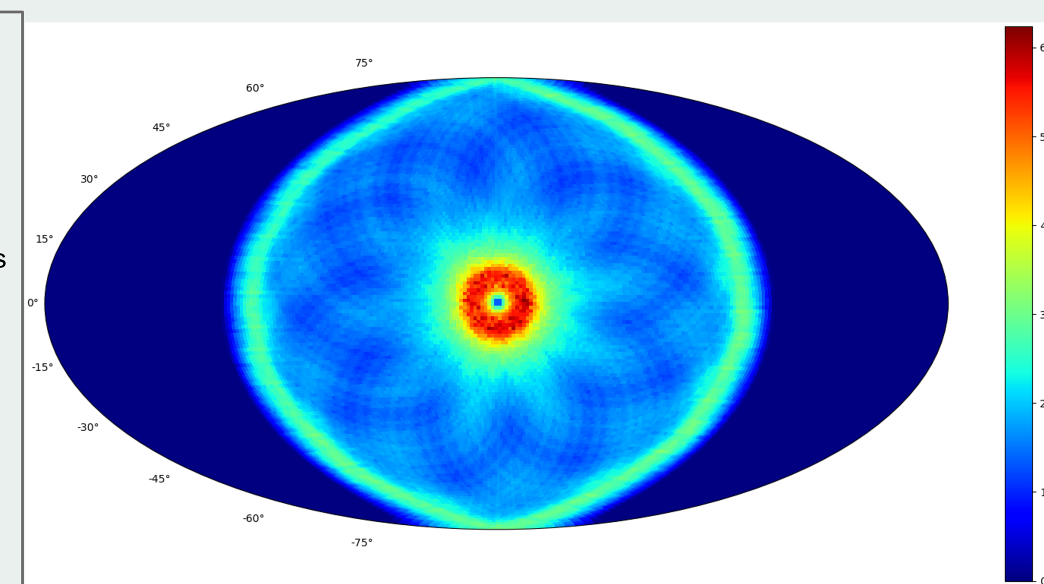
For each different LCS position relative to LB, the number of bolometers illuminated by the calibration signal emitted by the LCS has been determined.

- The more separated the different calibration signal traces are, the greater the percentage of viewed detectors .

It may not be necessary to reach all detectors with the calibration signal if they can be cross-calibrated.

The best option to place the LCS is close to the **anti-Sun axis**.

- The percentage of viewed detectors is around 60% for 12 hours but it reaches the 100% in that region for one day even when the LCS is at the same position.

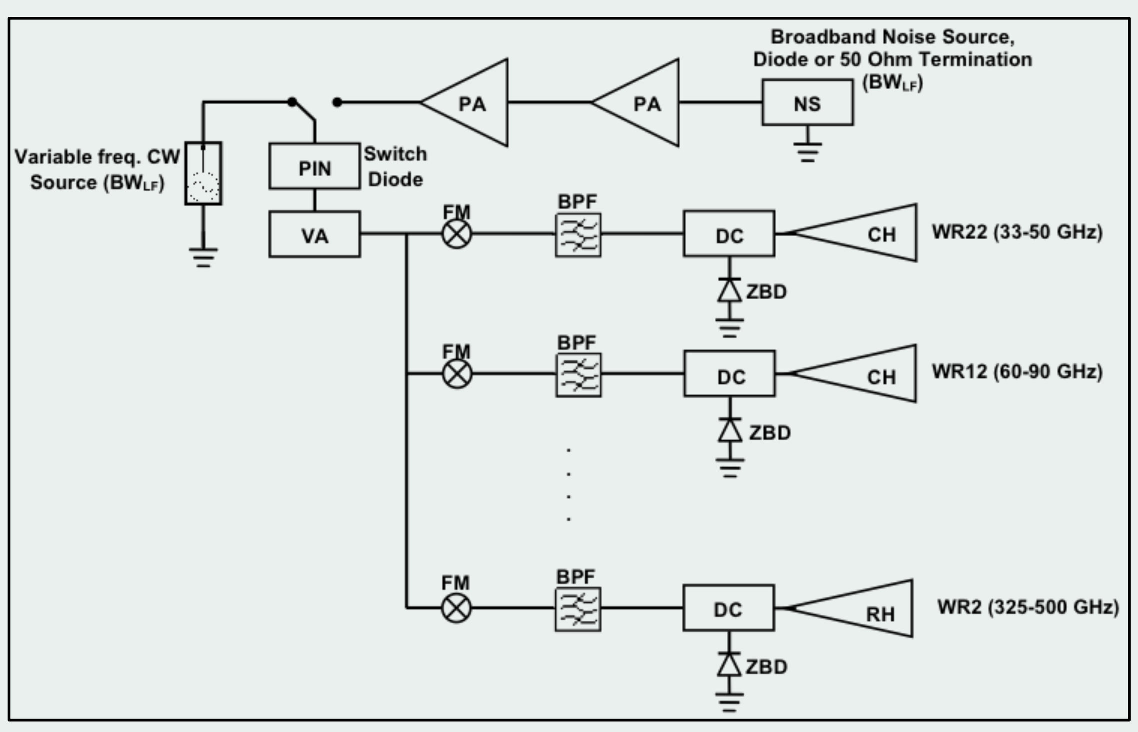


Percentage of viewed detectors according to the position of LCS relative to LB throughout 12 hours.

Payload: Calibration Source

Estimated Characteristics:

- **Volume: 10 cm x 10 cm x 20 cm**
- **Weight: 1.3 kg**
- **Power consumption: 50 W**



Cal. source diagram

Thermal Control and Power Budget

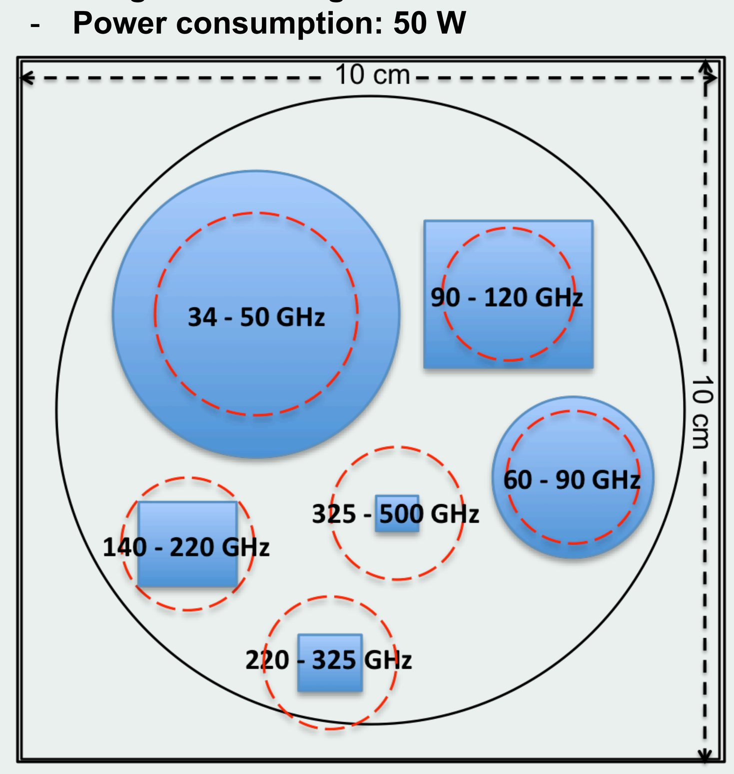
Table 3. Power arriving from Jupiter and L2-CalSat to a focal plane with 0.3 m aperture diameter. The calibration signal power (second column), the thermal power from L2-CalSat (third column) and the thermal power from Jupiter (fourth column) are shown. A Jupiter temperature of 160 K, fractional bandwidths of 0.25, Jupiter-Earth distance of 4.2 A.U. and distance between spacecrafts of 270 m, have been considered in the calculations

Freq. (GHz)	L2CS-Cal (nW)	L2CS-Th (pW)	Jupiter (fW)
40	13.2	0.2	2.2
100	0.8	2.8	33.9
400	0.8	179.1	2170

Table 4. Thermal power arriving from L2-CalSat (second column) and CMB (third column) to each detector. The saturation power of the detectors is shown in the fourth column. Fractional bandwidths of 0.25 and distance between spacecrafts of 270 m, have been considered in the calculations

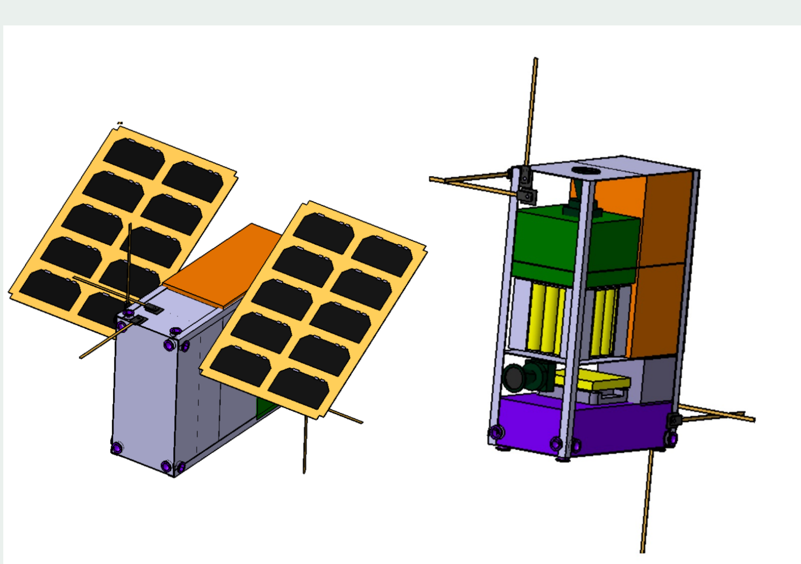
Freq. (GHz)	L2CS-Th (fW)	CMB-Pow (fW)	Sat-Pow (fW)
40	0.8	160	500
100	2.4	210	800
400	159	15	1200

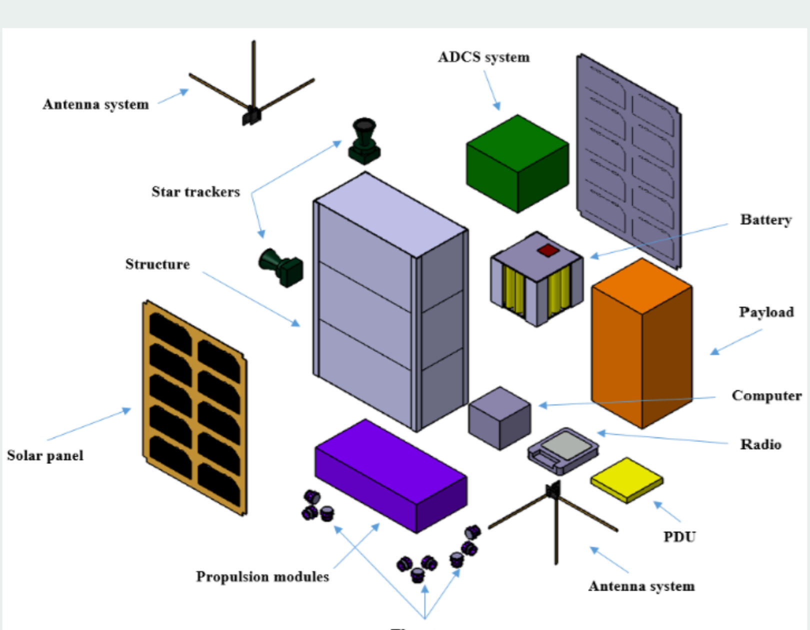
- Reflected thermal power has been calculated as 3 orders of magnitude lower than CMB power in the 400 GHz frequency band (worst-case).



Frontal view sketch

LCS Preliminary Design





Exterior view and exploded view of LCS.

LCS as a CubeSat (main option)

LCS has been pre-designed in IDR-UPM's Concurrent Design Facility (CDF). It has been designed as a piggy-back of the LB minimizing the impact in its architecture.

Main Specifications:

- Size: 6U Cubesat.
- Minimum distance between LCS and LB of 240 m;
- Calibration distance = 270 ± 3 m;
- Distance error determination < 13.5 cm;
- LB direction location error < 10'; LB orientation detection error < 1';
- LCS pointing error < 3';
- Power enough for 1 calibration per month;
- Minimum impact on LB (CubeSat deployer and 3 patch antennas).

Critical Technologies:

- Attitude control and determination: Sun sensors (Fine Sun Sensor) and star trackers (CubeSpace CubeStar).
- Metrology (relative position determination) and communications: RF ranging e.g. "Swift RelNav" by Tethers Unlimited.
- Propulsion: Cold gas thrusters (small and precise impulses with low consumption) e.g. GOMSPACE NanoProp.

Thermal Control:

- A preliminary LCS design implemented in the ESATAN® software shows a maximum temperature of 39 ºC in the solar panels.
- In the covered bandwidth by the telescope, this corresponds to a noise signal of 70 fW/pixel that is ten times below the LCS calibration signal at those frequencies.

Overall features:

- Total mass: 7.07 kg (dry mass) + 0.08 kg (propellant).
- Power: 2 orientable arrays of 6U-cubesat solar panels with a triple-junction technology by SpectroLabs.
- Total power generation: 57.2 W.

LCS as a microsatellite (alternative option)

If the piggy-back option is not viable, the concept of LCS can be extended to a microsatellite capable of reaching L2 autonomously (from the same launcher). The modification affects mainly to the propulsion and communication subsystems.

The **propulsion subsystem** is now composed of **two different types of thrusters**:

- Monopropellant thrusters (Hydrazine).
- MEMS thrusters (H_2O_2).

The **communication subsystem** must be capable of establishing contact with Earth by itself. Therefore, a high gain antenna will be required using **X band**.

The satellite mass is limited to 100 kg of which roughly 13% will be allocated for propellant, according to the propulsion subsystem specifications.

Features of alternative option:

System:

- Total mass; < 100 kg
- Propellant mass ratio; 13%

Propulsion:

- Thrust: 1 mN
- Impulse bit: 1 μN
- Isp: 215 s
- Propellant: Hydrazine/H2O2

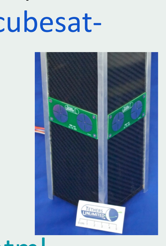
Communications:

- Band: X
- Antenna: Fixed high gain antenna

Impact In LB

Deployer: (6-Unit DuoPack (ISIS))

- Mass: 4 - 4.5 kg
- Deployement impulse: 1−2m/s CubeSatShop (3U)
- Power consumption: 1.75 A (28 V/250 ms)
- https://www.isispace.nl/product/duopack-cubesat-deployer/



Distance measurement (RealNav):

- Mass: 400 gr (including antennas)
- Size: 86x45 mm
- Power consumption: 2.5W average
- http://www.tethers.com/FormationFlying.html

OBC:

- Power consumption max: 2.3 W
- Mass: 80 g
- Size: 60x40x6.5 mm
- https://gomspace.com/UserFiles/Subsystems/datasheet…

Conclusions

- LCS is a feasible option that can increase the performance of LB.
- Among the different positions considered, the area close to the precession axis is the best option given the high levels of viewed detectors, access time, etc.
- The propellant required to maintain the LCS close to the anti-Sun axis is insignificant compared to the one needed for the transfer to L_2.
- LCS will not interfere with LB observations at any time of the mission.
- LCS as a microsatellite could potentially serve as a source of calibration for future telescopes in the L_2 libration point region, not only for LB.